



Use of animal density to estimate manure nutrient recycling ability of Wisconsin dairy farms

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Abstract

Animal density is increasingly being used as an indicator of agricultural nitrogen (N) and phosphorus (P) loss potential in Europe and the US. This study estimated animal-cropland ratios for over 800 Wisconsin dairy farms to: (1) illustrate the impact of alternative definitions of this ratio; (2) evaluate how the definition of 'cropland' would affect Wisconsin dairy farmers' ability to comply to manure N and P land spreading standards and (3) investigate the potential of using an animal density standard for targeting manure management plan implementation on Wisconsin dairy farms. Animal density calculations based on total cropland area indicate that 95% of Wisconsin dairy farmers have sufficient cropland for recycling manure according to a N-based nutrient management standard. Calculating animal density based on tilled cropland area decreases this value to 79% of dairy farms. Implementation of a

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P-based standard increases the land requirement for manure application, and a large proportion of Wisconsin dairy farms (37% based on total cropland and 75% based on tilled cropland) would lack sufficient land area for recycling manure P. When the area of cropland on which manure is actually spread is used to calculate animal density, it is clear that the majority of farms do not currently meet either manure N- or P-based land application standards. Reasons for not utilizing the full cropland base for manure application are unclear, but regional differences suggest soil texture, land tenure, and development pressures may limit the proportion of cropland receiving manure. These results indicate the need to better understand factors influencing cropland management and manure spreading behavior on Wisconsin dairy farms.

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1. Introduction

More than 40% of US waters are impaired and are unable to support basic uses, such as fishing and swimming (USEPA, 2000a). Agricultural non-point source pollution has been identified as the leading source of water quality impairment to surveyed rivers and lakes, and the nation's estuaries. While agricultural sources of non-point pollution include sediment, pesticides, salts and pathogens, nutrient pollution by nitrogen (N) and phosphorus (P) is identified as the leading impairment to water quality associated with agriculture (Shortle et al., 2001).

Although nutrient applications from animal manures or commercial fertilizers are necessary for plant growth and economic crop yields, when applied in excess of crop requirements they can become major sources of ground and surface water contamination (Beegle and Lanyon, 1994). Nutrient pollution from livestock manure is an increasing concern across the US. Recent trends towards larger and more concentrated livestock facilities (both geographically and in terms of animals per farm), and increased societal concern about agricultural pollutants have generated demands for a more rigid regulatory approach. This shift is most noticeable in the heightened attention toward the impact of livestock operations on water quality (USDA-USEPA, 1999), and increasingly stringent state regulation of livestock agriculture and manure management (Metcalf, 2000).

As demands for more controlled manure management heighten, policy makers seek indicators to assess the environmental impacts of livestock production and to subsequently direct manure management policy. Farm size indicators, based on number of animals per farm, are currently used to target federal manure management policy (USDA-USEPA, 1999). In this way, federal policy is directed toward the nations' largest livestock facilities. While recognizing the increased level of management needed to safely store and land apply very large amounts of manure, size-based indicators have been criticized for holding large livestock operations solely responsible for the majority of agriculture's pollution problems. The implicit assumption behind using herd size as a proxy for nutrient loss is that larger farms have a greater potential to cause environmental problems than smaller farms. How-

ever, the issue of whether large farms contribute disproportionately to pollution problems is increasingly unclear. It is often suggested, for example, that the economies of size, more modern technologies and potentially higher management skills associated with large-scale operations may actually put them at a decreased potential to pollute in relation to smaller, outdated facilities (Norris and Batie, 2000).

As it becomes increasingly evident that all farms, regardless of size, have an important role to play in protecting the environment from nutrient pollution, state and local policy makers have begun to cast the nutrient management policy net more broadly. In October of 2002, the Wisconsin state legislature passed a set of eight administrative rules and performance standards directed at the control and prevention of polluted runoff (WDNR, 2003). Agricultural-related pollution abatement efforts are directed toward controlling nutrient losses through the implementation of nutrient management plans on all Wisconsin farms by the year 2008. Nutrient management plans will only be mandatory, however, if the state provides at least 70% of the cost of pollution abatement technologies (e.g., buffer strips, manure storage and development of nutrient management plans), with cost-sharing monies initially directed toward designated water quality impairment zones. While Wisconsin and other states have a long history of using watershed-based indicators to target pollution abatement efforts, providing blanket cost-sharing coverage or technical assistance to farms within a watershed may not address operational features of a farm, such as animal density, that impact a farm's ability to recycle manure through cropland. Public and private sector costs associated with watershed-based or animal number indicators of pollution potential often increase as a result, which are not offset by the benefits of improving the impaired water resource (Shortle, 1999). Because funding is likely to become a limiting factor in implementing Wisconsin's non-point rules (Nowak, 2001), it is important that cost-sharing monies are directed toward operations most likely contributing to non-point pollution problems.

An alternative to herd size or location-based indicators for targeting nutrient management policy is animal density, expressed in terms of animals per unit area of cropland. Animal density is increasingly being used in Europe (Sibbesen and Runge-Metzger, 1995) and in certain parts of the US (Ribaudo et al., 2003). The strength of using animal density as a regulatory standard lies in its ability to provide a straightforward, relatively easy to calculate indicator of a farm's nutrient balancing potential. By characterizing the relationship of animal numbers (and the manure they produce) to the available cropland area for manure utilization, animal density addresses the core movement of nutrients within the dairy farm nutrient cycle (Bee-ple, 1994). Without adequate cropland on which to recycle manure nutrients, farms of all size have an increased potential for nutrient loss.

While the concept of using animal density as an indicator of nutrient balancing potential is fairly transparent, certain assumptions about feeding practices and the land base available for manure application need to be considered. For example, feeding practice can have a dramatic effect on manure P levels and the amount of land needed to recycle manure P (Powell et al., 2001). Also, it may not be reasonable to assume, given cropping practices and soil and climatic constraints, that all cropland would be available for manure application on an annual basis. In formulating

animal density standards, one must consider how to most accurately define the land base potentially available for manure application. The objective of this study was to investigate the implications of using alternative definitions of animal density standards to target nutrient management policy on Wisconsin dairy farms. Different conceptualizations of the land base available for manure application are developed and used to: (1) predict the ability of Wisconsin dairy farmers to recycle manure N and P through their cropland base, (2) explore the relationship between current dairy herd size, herd size expansion, and animal density levels, and (3) contrast cropland area potentially available for manure application with actual areas used to spread manure.

2. Materials and methods

In the late-winter and early-spring of 1999, a state-wide random survey of approximately 800 representative Wisconsin dairy farmers was conducted (Buttel et al., 1999). Data on dairy herd size, livestock inventories, and crop production were used to calculate animal densities (animal:land ratios).

2.1. Calculating animal/land ratios

2.1.1. Animal component

The animal component of the animal:land ratio (ALR) was calculated using animal unit (AU) equivalency factors, where 1 AU equals 454 kg animal live weight. Live weights of 635 and 410 kg were assumed for cows (both lactating and non-lactating) and heifers, respectively. Non-dairy livestock types and numbers were converted to AU equivalents using conversion factors published by the Wisconsin Department of Natural Resources (WDNR, 2002). Livestock operations included in the study had dairy (lactating and non-lactating cows and heifers) AUs comprising on average 87% of total livestock AUs on the farm.

2.1.2. Land component

The land area available for manure application was computed for each farm based on reported crop areas for the 1998 cropping season. The typical dairy farm in the sample operated approximately 110 ha of tillable land in 1998, with an average of 31 ha corn grain, 15 ha corn silage, and 49 ha hay. Three categories of cropland available for manure application were considered.

2.1.2.1. Total cropland. The sum of the land areas reported in each of the following crops: corn for grain, corn for silage, hay or haylage, small grains, soybeans, tobacco, and “other crops”.

2.1.2.2. Tilled cropland. The sum of the land areas reported in corn for grain, corn for silage, oats, barley and other small grains, non-hay “other crops”, 33% of the area reported in hay (this assumes that alfalfa fields are tilled every three years), and 65%

of the area reported in soybeans (the state approximate average for the annual proportion of total soybean area that receives some form of tillage).

2.1.2.3. Manured cropland. The reported amount of land on which manure was spread in 1998.

Based on the above definitions of animal units and land area, three different ALRs were calculated for each farm: (1) animal units:total cropland (ACLR), (2) animal units:tiled cropland (ATLR), and (3) animal units:manured cropland (AMLR).

2.2. Establishing animal density thresholds for manure nutrient balance

Low, medium, and high animal density categories (Table 1) were delineated based on the amount of N and P in manure and the average removal of these nutrients by a typical dairy cropping system. Annual manure N of an AU that needs to be recycled (i.e., average N losses in the barn and during storage already accounted for) was adapted from Klausner (1997) and manure P production from Powell et al. (2001) assuming manure from a cow fed a diet containing 0.38% P on dry matter basis, the approximate level of P fed on Wisconsin dairy farms (Powell et al., 2002). Animal density categories assume that all manure P is captured. The amount of manure P remaining in pasture, exercise lots, and uneven land spreading of manure are not considered. Also, estimations of nutrient balancing potential do not account for nutrient additions from legume N, commercial fertilizer, and existing soil nutrient reserves.

2.2.1. Low animal density

Dairy operations having less than 1.85 AU/ha would have sufficient cropland to recycle all manure P. However, crop N needs would not be met through manure applications alone. These operations should not face a significant degree of difficulty in implementing either N- or P-based manure management standards.

2.2.2. Medium animal density

Dairy operations having between 1.85 and 3.7 AU/ha have enough cropland to recycle manure N, but manure P would exceed crop P requirements. The ability of these operations to implement P-based nutrient management standards based on the P-index (Jarrell and Bundy, 2002) would, therefore, greatly depend on field by field soil test P levels, topography, and proximity to surface water.

Table 1
Calculated animal:cropland ratio threshold levels for Wisconsin dairy farms

Animal density category	Animal:cropland ratio (AU/ha)	Implication for nutrient management
Low	<1.85	Crop P requirements met by manure P, N deficit
Medium	1.85–3.7	P surplus, crop N requirements met by manure N
High	>3.7	P and N surplus, manure N and P exceeds crop requirements

2.2.3. High animal density

Even with the best manure management strategies, it would be nearly impossible for farms with animal densities greater than 3.7 AU/ha to apply manure to meet, and not exceed, crop N and P requirements. Alternative off-farm uses for excess manure and/or reductions in dairy herd size would have to be explored. This group of farms is extremely land-constrained, would have the greatest difficulty adhering to any nutrient management standard, and may have the highest potential to negatively impact the environment.

2.3. Statistics

Analysis of variance using [SPSS \(2001\)](#) was used to test animal:land ratio differences due to herd size expansion. Least significant difference at the probability level 0.05 was used to delineate significant difference among herd expansion class means. χ^2 tests ([SPSS, 2001](#)) were used to delineate differences in nutrient balancing potential of various animal:land ratios by animal density and herd size categories.

3. Results

3.1. Animal density by cropland category

The degree to which Wisconsin dairy farmers have sufficient cropland for recycling manure nutrients greatly depends on the definition of available cropland used to calculate the animal density ratio ([Fig. 1](#)). As the definition of available cropland

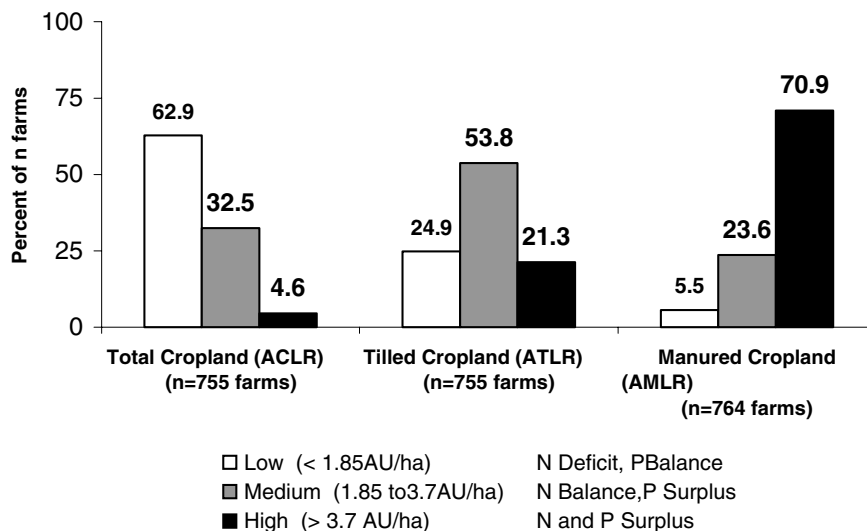


Fig. 1. Animal density and nutrient balance by cropland category on Wisconsin dairy farms.

used to calculate the ALR is increasingly restricted from total, to tilled, to actually manured cropland, the percentage of medium and high ALRs increases substantially.

ACLRs indicate that most (95%) Wisconsin dairy farmers have sufficient cropland for meeting N-based manure application standards, and 63% have sufficient cropland for meeting P-based standards. Under ATLR calculations, about 79% of farmers have sufficient cropland for meeting, and not exceeding crop N requirements. However, 75% of farms produce manure in excess of crop P requirements.

ACLR and ATLR indicators (Fig. 1) estimate a dairy farm's ability to recycle manure N and P based on the assumptions of N (Klausner, 1997) and P (Powell et al., 2001) availabilities, and that manure is applied evenly across each land type on an annual basis. AMLRs, on the other hand, take actual manure spreading behavior into account. Under AMLR calculations, about 71% of Wisconsin dairy farms apparently apply manure in excess of crop N and P requirements. Only 5.5% of farms fall into the low ALR category, which means actual spreading behavior meets P-based manure application standards. Approximately 24% of farms have medium animal densities and are able to meet N-based manure application standards, but manure applications would exceed crop P requirements. Farmer practices, such as manure collection, handling, storage, and land-application techniques, affect to a great extent manure N and to a lesser extent manure P content and therefore, calculations of ACLR, ATLR, and AMLRs.

3.2. Impacts of herd size and herd size expansion on animal density levels

3.2.1. Herd size

Having sufficient cropland for manure application at agronomic rates is a key aspect of nutrient management planning. Without an adequate cropland base livestock operations of all sizes are at risk of over-applying manure. Our χ^2 test shows that the distribution of animal density categories using ACLR is similar ($P < 05$) on dairy farms having herd size of less than 280 AUs (Table 2). Dairy farms having more than 280 AUs, however, have relatively more medium and high density farms, and fewer low density farms compared to other herd size categories. A similar pattern was observed using ATLR, except that the average proportion (53.5%) of farms in the medium animal density category on farms within herd size class of less than 280 AUs was similar (55.6%) to farms with herd size greater than 280 AUs.

3.2.2. Herd size expansion

Over the past few decades, Wisconsin's dairy industry has followed national trends (USDA, 2000) toward fewer but larger dairy operations. Dairy herd expansions resulting in greater than 1000 AU are regulated under federal permitting requirements (USEPA, 2000b). In Wisconsin, however, most dairy farms fall below this regulatory herd size level (Jackson-Smith and Barham, 2000). The majority of herd size expansions, therefore, occur outside any regulatory structure. As dairy operations expand, increases in herd size should be accompanied by increases in

Table 2
Nutrient balancing potential by herd size on Wisconsin dairy farms

Animal:land ratio	Animal density (nutrient surplus potential)	Herd size class (AU farm ⁻¹)					
		1–34 (<i>n</i> = 65)	35–69 (<i>n</i> = 242)	70–104 (<i>n</i> = 235)	105–139 (<i>n</i> = 88)	140–279 (<i>n</i> = 98)	280+ (<i>n</i> = 27)
% of farms within herd size class							
ACLR	Low	55.4	60.7	68.1	60.2	73.5	25.9
	Medium	36.9	35.1	29.3	34.1	22.4	55.6
	High	7.7	4.2	2.6	5.7	4.1	18.5
		100	100	100	100	100	100
ATLR	Low	23.1	22.7	25.5	26.1	32.7	11.1
	Medium	40.0	51.2	61.3	52.3	52.0	55.6
	High	36.9	26.1	13.2	21.6	15.3	33.3
		100	100	100	100	100	100

Table 3
Average animal:total cropland ratio (ACLR) by dairy herd expansion class

Herd expansion class ^a	(n farms)	ACLR (Mean)
Decrease or no change	367	1.63 b ^b
Expansion	370	1.98 a
1–25 cow increase	261	1.90 de ^b
26–50 cow increase	61	2.15 ce
51–100 cow increase	27	1.90 e
100 or more cow increase	21	2.54 c

^a Increase in cow numbers during period 1993–1998.

^b Column means followed by different letters are significantly different LSD_{0.05}.

the cropland base used for manure application, and/or alternative arrangements, such as manure export, that accounts for manure nutrient use is a sustainable way.

In Wisconsin, dairy herd expansion between 1993 and 1998 was not accompanied by a concomitant increase in cropland area (Table 3). Animal:cropland ratios on dairy farms that expanded (1.98) were significantly ($P < 0.05$) greater than on farms that did not expand (1.63), indicating that herd size increases were not accompanied by proportional increases in cropland area. The only exception to this was the herd expansion class of 51–100 cows which had a ACLR (1.90) not significantly different from non-expansion farms, likely due to the small sample size ($n = 27$) associated with this class.

3.3. The “manure gap”

Differences between ALR calculations based on total (ACLR) and manured (AMLR) cropland indicate the “manure gap”, i.e., the amount of cropland where manure can be potentially applied but is not. There are great regional differences

in the percentage of total cropland that receives manure (Fig. 2). The greatest contrast is between the northeastern and southwestern regions of the state. There are several important differences between these two regions that might affect manure spreading behavior. These include differences in soil texture, land tenure, and development pressures.

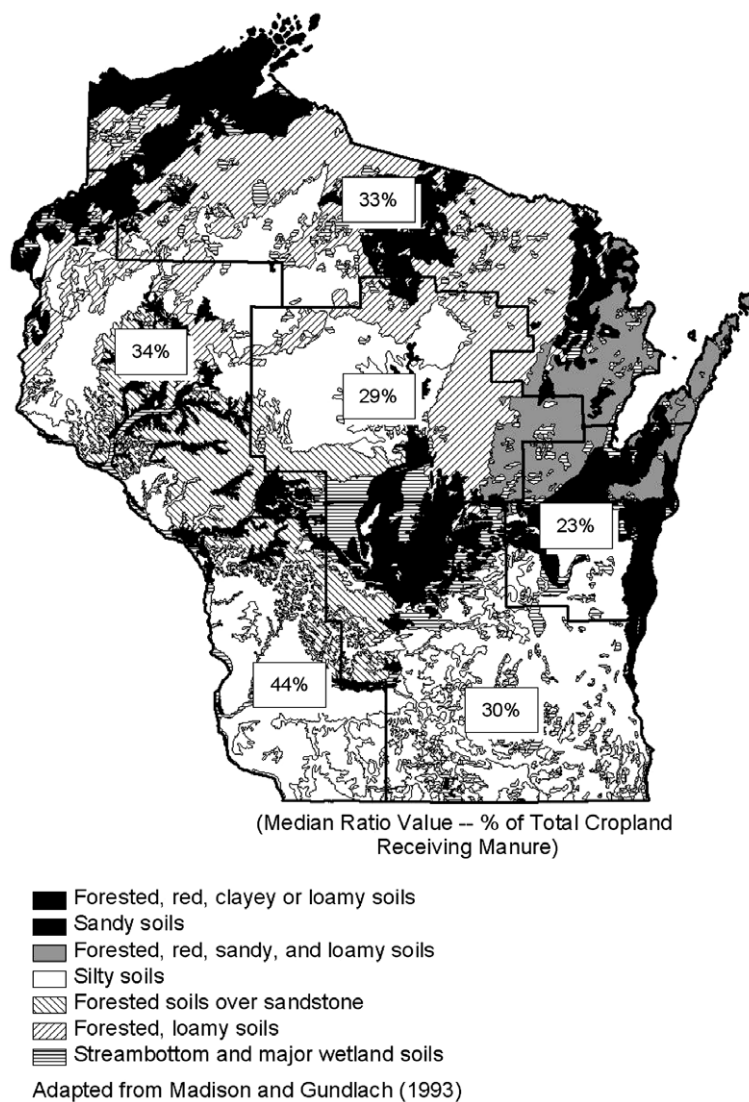


Fig. 2. Regional soil differences and percentage of total cropland that receives manure on Wisconsin dairy farms (Madison and Gundlach, 1993).

3.3.1. Soil texture

The southwestern region is characterized by silt loam soils that have relatively high permeability and drier field conditions in the spring and fall (Hole, 1976). By contrast, the northeast is characterized by more finely textured and less permeable clayey and red loam soils. Farms in the southwest, therefore, may have a wider “manure spreading window”, or number of days that soil conditions are favorable for manure spreading. Farmers in the southwest may therefore be able to access a larger proportion of their operated cropland acreage over a greater period of time than farms situated in the northeast.

3.3.2. Land tenure

Differences in land tenure, or the percentage of operated land that is owned, may also explain the regional differences in manure spreading behaviors. Among all farms in our sample, as the percentage of rented land increases, the proportion of cropland used to spread manure decreases (Fig. 3). Meanwhile, farmers in the southwest tend to rent smaller areas and thus own a greater proportion of their total operated land area than farmers in the northeast (Table 4). In general, the greater areas of rented land found on farms in the northeastern region may contribute to a decreased percentage of cropland that receives manure. Moreover, the travel distance between where the animals are housed (and where the manure is produced) and the location of rented land parcels can greatly affect whether or not rented land receives manure (Shepard, 2000). Spreading to distant, rented fields may be very time and energy consuming, and hence not an economically attractive option.

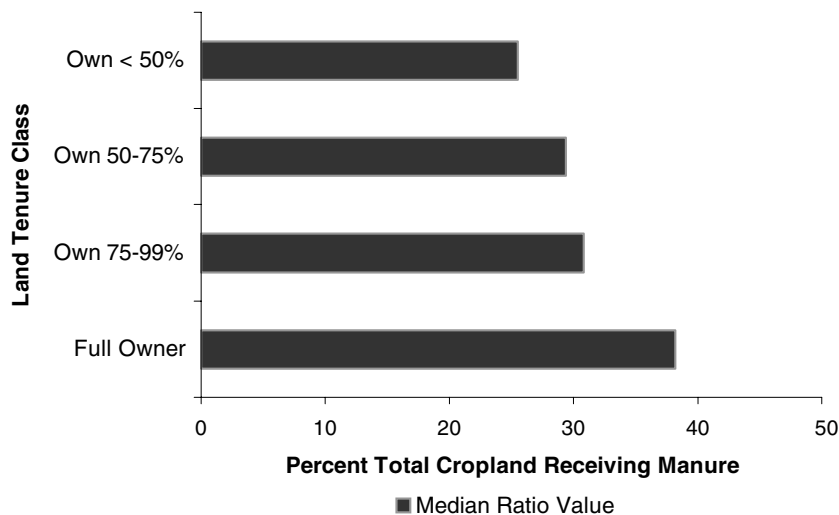


Fig. 3. Percentage of total cropland receiving manure by land tenure class on Wisconsin dairy farms.

Table 4
Regional differences in rented and owned cropland on Wisconsin dairy farms

Region	Mean rented cropland area (ha)	Cropland owned (%)
South	32	67.6
Southwest	16	76.9
West	22	76.1
Central	19	76.1
Northeast	28	68.7
North	21	61.4

3.3.3. Development pressures

As demographic changes that began with the 1960s movement into suburbia now carry over into traditionally rural landscapes (Norris and Batie, 2000), a dairy farmer's access to close-by or contiguous rented land parcels is becoming increasingly difficult. For example, rather than renting several contiguous fields from a single landowner, farmers are only able to rent fields in several different locations. Because there is a notable higher level of non-farm development pressures in the northeastern region of the state (PATS, 1998) farmers in that area may have greater difficulty finding access to close-by rented land parcels. Evidence from several on-farm follow-up visits suggest that farms in the northeast are more likely to rent fields more distant from the barn and more difficult to access without transporting manure on heavily traveled commuter roads. This could create additional disincentives for farmers in this region to spread on their rented cropland, compared to areas with lower development pressure.

4. Discussion

4.1. Definition of cropland available for manure application is critical

Both ACLRs and ATLRs provide an indication of the potential to balance nutrients between the livestock and cropping components of the dairy farm nutrient cycle, and hence comply with nutrient management standards that limit nutrient applications to either a crop N or P requirement. Actual manure spreading behaviors are not considered and it is assumed that manure is applied appropriately across all available cropland. ACLRs and ATLRs do vary, however, in the amount of cropland that is considered “available” for manure application. ACLRs consider 100% of the operated cropland area available for manure application and provide the most liberal estimation of nutrient balancing potential. ATLRs consider only tilled cropland available for manure application. The third animal:land ratio, AMLR, is based on the actual amount of land reported to have received manure over a one-year period. The ratio of AMLR (based on actual manure spreading behaviors) to ACLR or ATLR (based on nutrient balancing potential) indicates the percentage of available

cropland actually receiving manure versus potentially available cropland, or the manure gap.

Animal density standards must consider the percentage of cropland actually available for effective manure application. ATLRs are favorable in the sense that they take into account cropping patterns, tillage practices, and the recommendation that manure be incorporated into soil to conserve its fertilizer N value (Meisinger and Jokela, 2000). On average, tilled cropland accounts for about 64% of the total cropland acreage on dairy farms. From a regulatory point of view, however, the implementation of an ALR standard based on tilled cropland may cause shifts in cropping or tillage practices to maximize the amount of land that is considered tilled and therefore “spreadable.” While moving fields out of hay and into more row crops may provide more tilled land for spreading manure, it is also important that ALR standards work in conjunction with farm conservation plans.

While the degree to which Wisconsin dairy farms lack sufficient cropland for recycling manure nutrients depends on how one defines the animal density threshold, only 5–20% of Wisconsin dairy farms, based on ACLR and ATLR calculations, respectively, lack sufficient cropland for spreading manure according to a N-based manure application standard. The implementation of a more restrictive P-based standard will reduce the amount of manure that can be applied to cropland. A large proportion of Wisconsin dairy farms (37% on total cropland basis, 75% based on tilled cropland) apparently lack sufficient cropland for meeting more restrictive P-based manure application standards. We reiterate that our estimates of nutrient balancing potential based on total or tilled cropland do not account for nutrient additions from legume N, commercial fertilizer, and existing soil nutrient levels. The addition of any of these nutrient inputs would decrease the need for manure to maintain a balance between nutrient input and crop nutrient removal, and therefore increase the total cropland requirement for spreading manure produced by the whole herd.

Results of this study indicate a large gap in knowledge of manure spreading behavior on Wisconsin dairy farms. High animal density levels are prevalent, especially on operations that have experienced herd size expansions (Table 3). Animal density would provide a useful, and size-neutral indicator for targeting regulatory oversight. High animal density farms likely have the greatest difficulty in meeting any nutrient management standard and may have to seek ways to reduce nutrient loads in manure through diet manipulation, expanding their land base for manure spreading, exporting manure off their farm and/or reducing animal numbers (Powell et al., 2002). An animal density standard would also provide a much-needed framework for planning dairy herd expansions.

Setting an animal density standard would require some initial consideration of how to define the land base considered available for manure application, and whether a N- or P-based application standard is used. However, the development of an animal density standard based on realistic goals for reducing nutrient losses may have certain carry-over benefits that would help promote the long-term sustainability of Wisconsin's dairy industry. In general, being able to match livestock numbers with an adequate land base for manure application is an important part

of good nutrient management. It creates a balance between the number of animals, the amount of forage and grain they need and the amount of manure produced, thereby reducing the need for off-farm feed purchases, manure exportation, and the overall likelihood of nutrient accumulation and loss. In Wisconsin, farms with stocking rates of less than 1.54 AU/ha (55% of all farms) are self sufficient in forage and grain production and have more than adequate land for manure spreading (Powell et al., 2002).

4.2. Biophysical and development constraints likely influence manure spreading areas

ALRs based on “manured” cropland indicate that major adjustments in manure spreading behavior need to be made if dairy farmers are to adhere to N- or P-based manure application standards. In instances where a large manure gap exists (i.e., considerable available cropland not being utilized for manure application), nutrient balance may be achieved through a greater utilization of the available cropland base, especially tilled cropland.

While many Wisconsin dairy farmers apply manure and fertilizer N and P in amounts that exceed crop nutrient requirements (Nowak et al., 1997), the factors that shape this behavior are less well understood. Regional analysis of the manure gap suggest that differences in soil texture, land tenure, and development pressures may be major factors that influence the percentage of operated cropland that receives manure. Additional research needs to be conducted to fully understand these implications.

5. Conclusions

While there are various approaches to developing manure management policy, an animal density indicator may be particularly appropriate for Wisconsin's dairy industry. Most farms continue to integrate crop and livestock production and have the potential for on-farm recycling of manure nutrients. From a policy perspective, animal density can be accurately assessed on each farm at low costs and may provide an easy tool that signals the need for policy action.

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